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THE INVESTIGATIONS ON ALUMINIUM SUBSTRATES COATED WITH MICRO-SIZED WC-CO /CR_3C_2-NICR MULTI-LAYERED HARD COATING

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ABSTRACT

The aim of this paper is to analyze the enhanced properties of aluminium substrates by coating with multilayered hard coatings. In this study, coating containing alternative filmy layers of micro-sized chrome carbide–nickel chrome (75:25) and tungsten carbide – cobalt (88:12) are coated on LM 9 aluminium substrate using high-velocity liquid fuel (HVLF) spray technique. The results indicate that multi-layered coating has shown good mechanical properties with significant improvements in the hardness and porosity with the coating strength as prescribed for use in IC engines. The mechanical properties of multilayered coating are strongly affected by number of coating layers.

KEYWORDS: Aluminium Substrates, Multi-Layered Hard Coating, High-Velocity Liquid Fuel (HVLF) Spray Technique, Chrome Carbide– Nickel Chrome (Cr_3C_2-Nicr), Tungsten Carbide-Cobalt (WC-Co) & Mechanical Properties

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Original Article

INTRODUCTION

The Major challenge of the future automotive industry is the fuel economy of engines. Fuel economy is impacted by two main factors namely; weight of the automobile and friction loss in the engine. Frictional losses account for over 40 % of total power of the vehicle with most of the losses occurring due to frictional loss between piston rings and engine bore. In high performance vehicles, the powertrain weight can make up upto70% of the total weight of the car. This heavy engine block adversely affects the vehicle’s centre of gravity and the handling characteristics and also affects fuel consumption.

Cast-iron and steel components of the engine can be replaced by aluminium parts to reduce the engine weight and other accessories Since the weight of aluminium is about 35% the weight of iron and hence, the weight of an engine can be reduced to a third of its original weight if all the components are made of aluminium instead of cast-iron. However, the process isn’t as simple as swapping out cast-iron with aluminium since aluminium is extremely soft and highly susceptible to abrasive wear and tear. The aluminium surface possesses poor friction and wear characteristics when compared to conventional cast iron. This problem limits the scope of using aluminium in the engine for components where excessive motion is present, such as pistons, cylinder liners, crankshaft, tappets, cams, followers, etc. Hence, aluminium can only be used in reducing the weight of the engine block. However, by making aluminium more resistant to wear and by increasing its hardness, it can be used in multiple components of the engine. There are many ways on increasing the hardness and wear properties of aluminium. Some of them are

metallurgical, such as anodising, surface hardening and tempering etc. and also by alloying. The other method of improving the properties of aluminium is by using hard coatings which can radically enhance the hardness and reduce the surface of aluminium substrates.

In earlier days dangerous hard chromium plating technology was commercially used in the automotive applications to improve wear resistance. The main disadvantage of hard chrome plating is hazardous Chromium ion (Cr^{+6}) used in the galvanic process which is deleterious to the environment and human health. Amongst the thermal spray coatings for improving anti- wear and anti-friction properties, the cermet (ceramic and metallic materials composite) coatings are the most extensively used spray coatings. Initially, thermal sprayed Cr_3C_2 –NiCr (75:25) coatings replaced hard chrome plating to reduce wear and friction coefficient of automotive parts.

Aluminium substrates coated with diverse types of materials has been studied for improvement of mechanical properties by several researchers [1-30]. Materials such as Alumina (Al_2O_3), Titania (TiO_2), Tungsten carbide with cobalt as a binding materials (WC-Co) in the ratio of 88:12, chrome carbide with binder materials nickel chrome (Cr_3C_2-NiCr) (75:25) and the combination of several metallic & ceramic materials have been widely researched as coating materials. Several coating techniques such aslaser re-melting, high velocity air-fuel (HVAF), high velocity liquid fuel (HVLF), high velocity oxygen fuel (HVOF), plasma coating etc., are conducted to study their effect on the mechanical properties.

Bobzin et al. [1], proposed a new approach to coat cylinder liners by using thermal spray coating, and to provide a suitable running surface. Cr_3C_2-NiCr (75:25) coatings were applied on the substrates with specifically designed thermal spray systems to coat internal bores. The microstructure of the coating and the coating properties were analyzed and it is found that found tribological performance of coating improved by proper selection of coating parameters.

Sidhu et al.[20, 21] investigated wear characteristics of HVOF spray coating of Cr_3C_2-NiCr and WC– Co on Fe-based steel substrate. The surface wear is evaluated on a tribometer and it is found that the performance of WC–Co coating is excellent compared to Cr_3C_2-NiCr coating. This improvement is related to uniform and dense microstructure resulting in high hardness of WC-Co Coating. The reason for improved properties is found to be due to presence of oxide layer on the coatings.

Suarez.et al. [23] investigated anti-corrosion properties of 450µm thick Cr_3C_2-NiCr annealed coatings on the steel surface. It is concluded that at 800^{o}C the annealed coating has improved corrosion resistance than that of the asdeposited coating. The coating corrosion density after annealing was 3 to 4 times lesser than that of as-deposited coating on the steel surface.

Vashishtha and Sapate [25-27] investigated the abrasive wear behavior and coefficient of frictionof WC-12Co and Cr_3C_2-NiCr of thermal spray coatings using wear maps to spot the change in abrasive wear rates and harshness of oxidative wear. It was concluded that the wear mechanisms, operational conditions, micro-structure and the degree of oxidation affects wear and friction.

Zhang et al. [29] have done an experimental investigation on the failure mechanisms and the rolling contact fatigue (RCF) resistance at different contact stresses of Cr_3C_2-NiCr coatings. After conducting fatigue tests at various contact stresses, with the help of Weibull plot distribution, it is found that the fatigue life of CrC–NiCr cermet surface coatings decreased with increase in contact stress.

Present Investigations on Multi Layered Coating

Single layer Cr_3C_2-NiCr and WC-CO coatings on aluminium substrates have their own advantages and disadvantages. Cr_3C_2-NiCr coating withstands corrosion at high temperatures existing in automotive engines but have inferior properties compared to WC- Co Coating. The main disadvantage of WC-Co coating is their ineffectiveness at temperatures beyond 400^{o}C making them unsuitable to IC engines. The present studies explore the performance of thermal sprayed micro sized multilayered Cr_3C_2-NiCr and WC-CO coatings on aluminium substrates which inherit the advantage of both coatings. The studies are conducted for improvements in micro-hardness and adhesion strength of coating. The studies are made in terms of improvements in porosity, micro-hardness and adhesion strength of coating. The effect of mechanical properties by increasingnumber of layers of coating is examined.

MATERIALS AND PROCESS

In the current studies, Aluminium (LM 9) is taken as the substrate material. Materials for coating are WC-Co (88:12) and Cr_3C_2-NiCr (75:25) agglomerated and sintered powders purchased from M/s Inframat Corporation. The loose agglomerates of micro sized Cr_3C_2 – NiCr and WC-Co particles can be seen in Figures 1a&1b. The coating is conducted on aluminium substrates by high-velocity liquid fuel (HVLF) spray technique. The adhesive used fortesting the adhesion strength of the coating is purchased from 3M adhesives.

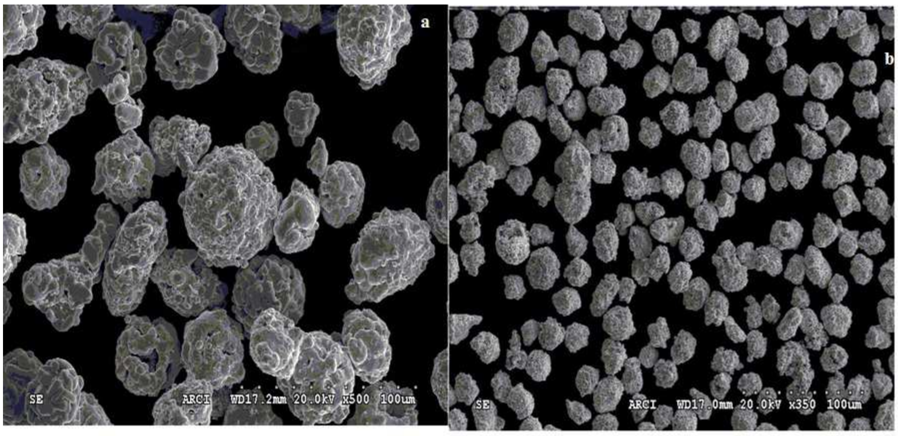

Figure 1: HRSEM Images of Agglomerated Powders a) Cr_3C_2 – Nicr (75:25) b) WC – Co (88:12)

Coating Procedure using HVLF Spray Technique

Grit blasting of the specimen surface was done before coating the material to facilitate immediate attaching of coating material after impingement on specimen surface. The metal discs and liners are cleaned thoroughly using Isopropyl alcohol and a white LINT FREE cloth. The specimens are placed in a grit blast furnace and grit blasted using dry air and alumina particles of 24 grit size as per following conditions.

Air pressure: 5 bar

Blast Angle: 45-60^{o}

Air Nozzle Distance: 6 inches

Time of blasting: 30 minutes

Preheating of nano structured WC – Co powder before coating:

The coating materials were preheated to remove moisture. After preheating, the powder is loaded in the HVLF or plasma gun for spray coating

High velocity liquid fuel spray coating procedure:

In a HVLF process, fuel and oxygen are ignited and the combustion byproducts reach a temperature of 2700ºC, melt the spay powder and imping it on the aluminium substrates uniformly at a velocity close to 2200 m/s. The spraying parameters are accurately governed to enable parameters enables high quality coatings. The schematic of the HVLF technique is depicted in Figure. 3

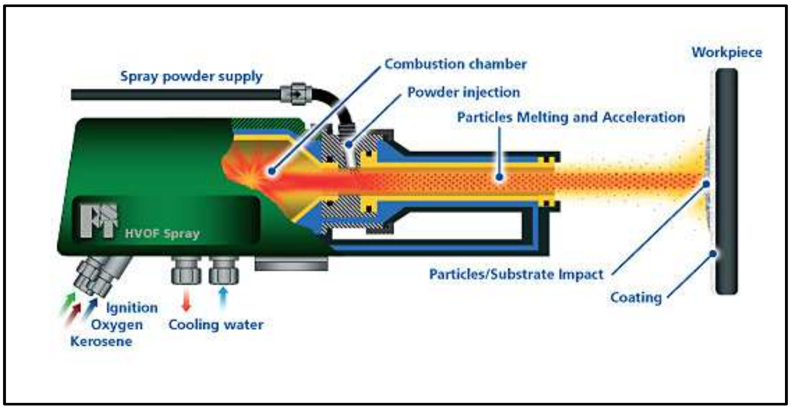

Figure 2: Schematic of the HVLF Technique

Treatment after Coating

After the coating, the discs are carefully washed with a solvent to remove the spray byproducts on the surface. It is ensured that the coating is free from smoke, masking tape, damages and contamination. The discs are honed using diamond tool to a perfect finish similar to automobile liners. The dimensional tolerances and accuracy are ensured using micrometer.

CHARACTERIZATION OF COATING AND DISCUSSION OF RESULTS

The Aluminium discs after spray coating with HVLF method to a thickness of 300 – 350 µm is honed with a diamond tool to a thickness of 250-275 µm to achieve smooth surface. The coatings are visualized using high resolution scanning electron microscope (HRSEM) to assess the structure of coating and the micrographs are shown in Figures 3 to 6.

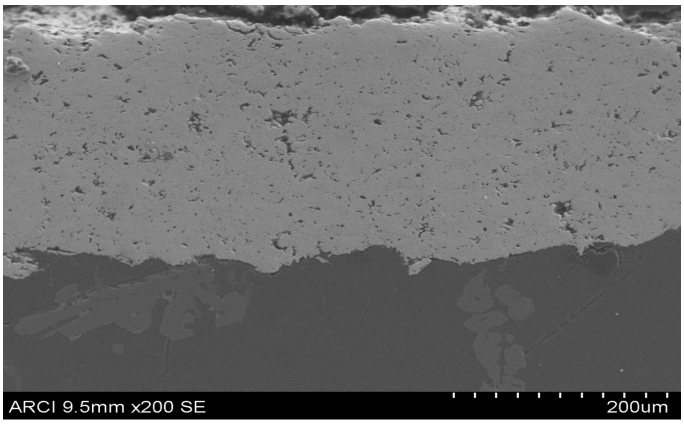

Figure 3: HRSEM Micrograph of Coating Cr_3C_2 – NiCr (75:25) on Aluminium Disc

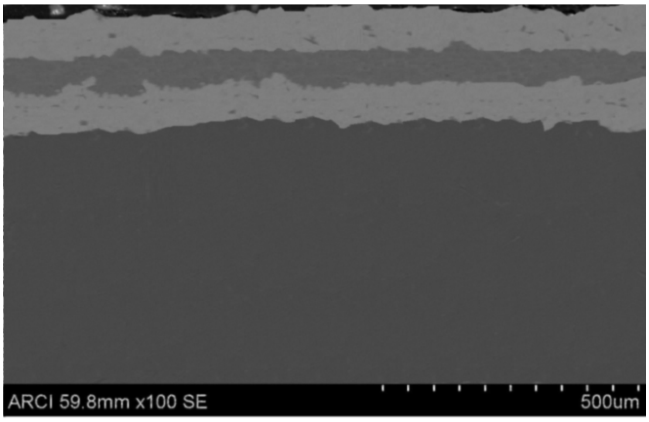

Figure 4: HRSEM Micrograph of Alternative Filmy Layers Graded Coating (3 Layers) With of Cr_3C_2 – NiCr(75:25) and WC – Co on Aluminium Disc Along Coating

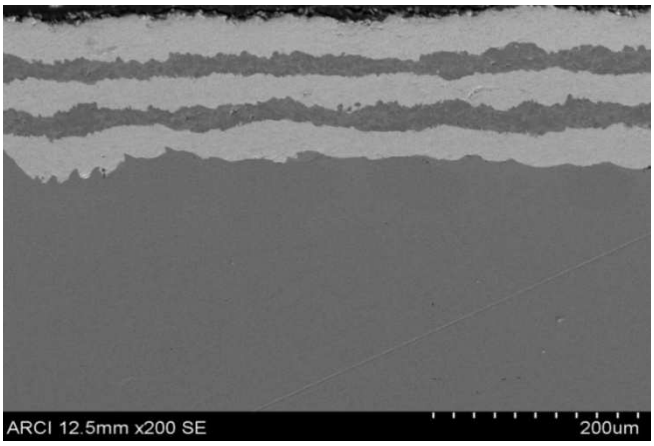

Figure 5: HRSEM of Coating of 5 Layered Graded Coating with Alternative Filmy Layers of Cr_3C_2 – NiCr(75:25) and WC – Co on Aluminium Disc Along Coating

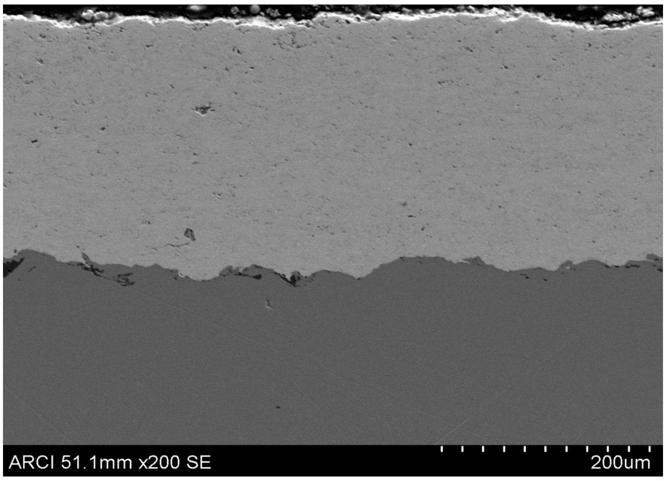

Figure 6: HRSEM and EDX Micrograph of WC – Co Coating on Aluminium Disc along Coating

All the figures indicate a compact and regular microstructure with a porosity range of 2 to 3 %. The borderline between the coating and disc material is also free from micro-cracks indicating optimum coating parameters. A good cohesion of coating and substrate can be found in all the coatings due to intensive kinetic energy attained by the coating materials during the coating process.

Porosity of Coatings

The porosity of the coating is deeply related to its hardness and a value of porosity lower than 1% indicates good hardness. A higher value of porosity will result in the reduction of hardness of coating which will lead to cracks in the coating. The coatings are characterized for porosity using metallurgical microscope and reported in the table given below

Table 1: Porosity Values of All the Coatings

Specimen	Coating Thickness, μm	Porosity, %
Cr_3C_2 – NiCr (75:25)	266	3.54
Multi-layered coating with 3 layers	281	2.57
Multi-layered coating with 5 layers	254	2.22
WC – Co (88:12)	264	2.31

Test for Micro Hardness and Adhesion Bond Test

Micro hardness test measures the hardness of materials and their resistance to distortion and wear & tear. Micro hardness correlates directly to the strength of the coating and a value of 400 to 500 HV is desirable for automotive applications. Micro hardness also called micro indentation hardness testing is used to specify the toughness of materials under mild applied loads. In micro indentation hardness testing, the specimen surface is impressed with an indenter of specific geometry mase of diamond with a specified of force ranging from 1 to 500 gf. The hardness number is can be calculated by measuring the indentation on the surface. Micro hardness test is performed as per ASTM E 384 and the values are tabulated in Table 2.

Table 2: Coating Thickness and Hardness Values

Specimen	Coating Thickness, μm	Porosity, %	Micro Hardness (HV)
Cr_3C_2 – NiCr (75:25)	266	3.54	754.32
Multi-layered coating with 3 layers	281	2.57	837.32
Multi-layered coating with 5 layers	254	2.22	978.32
WC – Co (88:12)	264	2.31	1025.12

From the above results it can be observed combination of materials in the multiple layers of Cr_3C_2-NiCr and WC-Co coatings significantly improved the hardness. Porosity is found to have decreased with increase in number of layers due to better adhesion which is also a contributing factor in increasing the hardness of the film coating. It can also be observed that the hardness and porosity of the 5 layered coating is almost same as WC-Co (88:12). Adhesion bond testing is often used to determine if the coating adhered properly to the substrates on which they are applied. The adhesion strength can be assessed using an adhesion test conducted as per ASTM D 4541. In automotive engines, the cylinder bore is subjected to tremendous forces also the radial surface and a coating is required to withstand those forces. This test can estimate the magnitude of the greatest perpendicular force that can be applied on the coating surface area that cause detachment of the coating material. It also decides whether the surface is undamaged after application of the force and determines success or failure of coating. A loading fixture is secured normal to the coating surface with an adhesive (Scotch Weld Adhesive) and allowed to dry. A tensile force is applied to the loading fixture and gradually increased till failure of the coating. A normal value in the range of 60 Mpa is essential for Internal Combustion Engines. In the current investigation all the coatings could withstand a maximum load of 85 Mpaapplied on the surface. Table 3 shows the values of adhesion strength of coatings

Table 3: Adhesion Strength of Coatings

Specimen	Adhesive Strength, (Mpa)
Cr_3C_2 – NiCr (75:25)	>85 Mpa
Multi-layered coating with 3 layers	>85 Mpa
Multi-layered coating with 5 layers	>85 Mpa
WC – Co (88:12)	>85 Mpa

CONCLUSIONS

- The thermal spray parameters are properly selected that produce low porosity coating with good cohesion between the coating and substrate.
- The strength of Chrome carbide – Nickel chrome coating is found to have improved by coating alternative layers of Cr_3C_2 – NiCr and WC – Co thereby improving cohesion, reducing porosity which resulted is excellent mechanical properties.
- Multi layered coatings possessed low porosity and enhanced hardness with a good adhesion strength
- The number of layers in multi layered coatings influences the enhancement of the mechanical properties of penta-layer coating gave best properties.
- Multi layered coating with five layers possesses properties comparable with WC – Co coating with abenefit of operation at high temperature.

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